Device of a Compact Microstrip Patch Antenna for Ultra-Wideband Applications

Md. Naimur Rahman[1, a*], Mohammad Tariqul Islam[1, b], Md. Zulfiker Mahmud[1, c], Md. Samsuzzaman[2, d]

[1] Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia.

[2] Department of Computer and Communication Engineering, Patuakhali Science and Technology University, Patuakhali, Bangladesh.

Email: [a]p86256@siswa.ukm.edu.my

[b]tariqul@ukm.edu.my

[c]zulfikerm@siswa.ukm.edu.my

[d]sobuz@pstu.ac.bd

[*]corresponding author: p86256@siswa.ukm.edu.my

***Abstract*—** This paper presents a novel and compact, broken heart shaped patch antenna aimed to use in UWB applications. The mentioned antenna is composed of a broken heart shaped patch and slotted ground plane. The antenna is impersonated on an FR4 material which has a depth of 1.60 mm and the relative permittivity of 4.4 with dielectric loss tangent of 0.02. The antenna is fed with a 50Ω feed line. The mentioned antenna has a close-packed dimension of 30 mm × 18 mm × 1.6 mm. The mentioned, broken heart shaped antenna is simulated and analyzed by both the High Frequency Structure Simulator (HFSS) and the Computer Simulation Technology (CST). After the fabrication, the prototype is measured. The results exhibit that the reflection coefficient less than -10dB covers the frequency range from 2.90 GHz to 10.70 GHz (115%) maintaining VSWR≤2. The maximum gain of the mentioned antenna is 5.28 dBi with a considerable efficiency.

***Keywords*—**Broken Heart shape, Concise antenna, Slotted Ground Plane, Ultrawideband (UWB).

1. Introduction

Now a day, IEEE 802.15 standard recognized frequency ranges from 3.1 GHz to 10.6 GHz have been utilized in wireless communications for low cost, low complexity, and high data rate. Compact sized front-end printed circuit board antenna has growing demand as it occupies reduced antenna dimension maintaining or increasing larger bandwidth [1]. The Ultra-Wide Band (UWB) provides a lot of advantages that includes higher data rates, increased communications, security and low interference to legacy systems. It is still a challenge to design an electronically small, considerable gain and efficient UWB antenna [2]. Quite a lot of microstrip patch antenna has been mentioned for UWB applications. Many of these antennas are either large or do not cover a large bandwidth. For instance, a printed crescent shape patch antenna has been reported in [1] covers the entire UWB bandwidth but occupies a larger dimension of 31 mm × 31 mm × 1.57 mm. In [2], a heart-shaped monopole antenna has been mentioned which covers 2.70 GHz to 26.0 GHz but it occupies the dimension of 40 mm × 48 mm × 1.5778 mm. A heart shaped patch antenna has been presented in [3] which occupies a dimension of 25 mm × 21 mm × 1.00 mm, but it has two notch band which means this antenna doesn’t cover the entire band of UWB. Gokmen Isik et al. [4] execute an experiment on heart shape UWB antenna with triangular patches which occupies a dimension of 25 mm × 26 mm × 0.50 mm. Rather it does not cover the lower band of the UWB bandwidth. In [5], a heart shape antenna has been presented which cover the bandwidth from 2.1 GHz to 11.5 GHz but it has a larger dimension of 35 mm × 30 mm × 1.00 mm. A tapered shape antenna has been reported in [6] which covers 3.0 GHz to 11.2 GHz. The antenna presented in [7] having a larger dimension of 31 mm × 25 mm × 1.60 mm, does not cover the entire UWB bandwidth as it has five notch band. A CPW fed UWB antenna has been mentioned in [8] which has a dimension of 40 mm × 50 mm × 1.60 mm, and it failed to cover the entire UWB bandwidth. In [9], a compact disk monopole antenna has been presented which covers the entire UWB bandwidth with a relatively larger dimension of 35 mm × 30 mm × 0.83 mm. The antenna presented in [10] covers the bandwidth from 2.78 GHz to 9.78 GHz with a larger dimension of 50 mm × 42 mm × 1.50 mm. The antenna, presented in [11] with a larger dimension of 62.9 mm × 50 mm × 1.6 mm failed to cover the UWB band. In [12], a compact size planar antenna covers the UWB but has a lower gain. In this paper, a novel broken heart shape antenna with a compact dimension of 30 mm × 18 mm × 1.60 mm only is mentioned which is significantly smaller than the antenna reported in [1-2], [4-5] and [7-11]. The result reveals that the mentioned antenna can conceal a bandwidth from 2.90 GHz to 10.70 GHz that is usable for the UWB applications.

2. Antenna Design and parametric study

Designing a compact and facile antenna which exhibits little distortion having enormous band spectrum is a challenge as it is the most fundamental component in UWB systems. Fig. 1 embellishes the mentioned broken heart shape antenna. The antenna composes of a broken heart shape patch with the slotted ground plane.

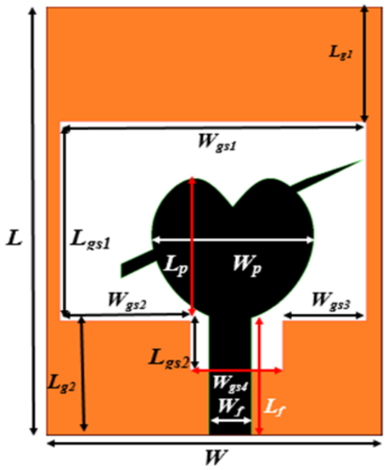


Fig. 1. Layout of mentioned antenna structure

The broken heart shape patch of the mentioned antenna is impersonated on one part of an FR4 substrate. The substrate has a compact size of L × W having a depth of 1.6 mm containing a relative permittivity of 4.4 with 0.02 loss tangent. A microstrip line having length L_f and width W_f is imprinted on the similar part of the substrate which acts as radiating component. The slotted ground plane is imprinted on the opposite part of the FR4 material. The radiating patch is composed of a broken heart shape patch to achieve maximum bandwidth. An SMA connector is attached to the base of the 50 Ω microstrip feed line. The change of patch structure of the mentioned antenna causes the change of capacitance and inductance of the input impedance for which the bandwidth changes. The size and structure of the broken heart shape patch can control the resonance characteristics of the radiator because this structure influences the coupling between the patch and the ground. The ground is slotted to achieve better impedance bandwidth. The parameters of the mentioned antenna are as like: $L=30$ *mm*, $W=18$ *mm*, $L_f=8.3$ *mm*, $W_f= 2.3$ *mm*, $L_{g1}=8.00$ *mm*, $L_{g2}=8.00$ *mm*, $L_{gs1}=14.00$ *mm*, $L_{gs2}=3.4$ *mm*, $W_{gs1}=16.5$ *mm*, $W_{gs2}=7.00$ *mm*, $W_{gs3}=4.5$ *mm*, $W_{gs4}= 5.00$ *mm*, $L_p= 9.60$ *mm*, $W_p= 8.7$ *mm*. The geometric parameters of the antenna can be well stable to achieve return loss over a wide bandwidth. The broken heart shape of the patch can produce multiple resonances providing wider bandwidth.
Fig. 2 displays the payoff of the slotted partial ground and broken heart shape of the patch on the presented antenna in terms of reflection coefficient.

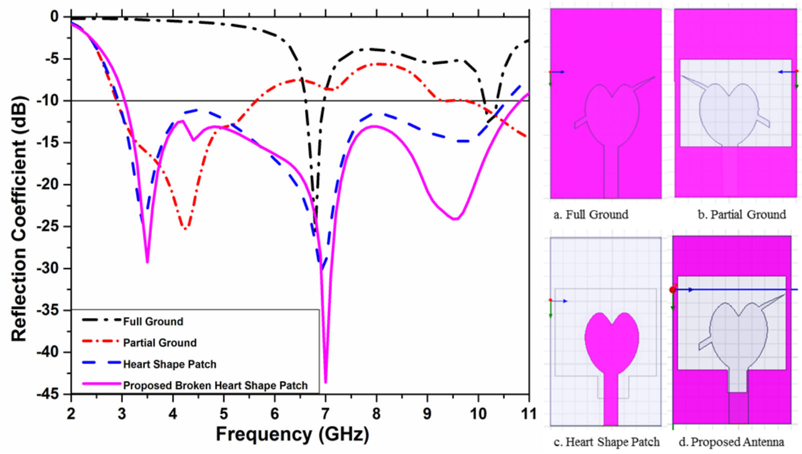


Fig. 2. Effect of defective ground plane and broken heart shape patch in terms of reflection coefficient.

It is observed that the reflection coefficient is much higher than -10 dB for the full ground plane and hence only one resonant frequency is found covering quite a small frequency band. For the partial ground plane, only one resonant frequency is observed at 4.2 GHz but does not cover the entire UWB. Occupying the heart shape microstrip patch with a defective partial ground plane, the bandwidth is enhanced. Here two resonant frequencies are found at 3.5 GHz where S11 < -25dB and at 6.9 GHz where S11 < -30 dB. But by using the mentioned broken heart shape microstrip patch, the antenna covers the entire UWB generating three resonant frequencies at 3.5 GHz where S11 < -30 dB, at 7 GHz where S11< -45 dB and at 9.5 GHz where S11 < -25 dB. For the partial ground plane, the antenna size becomes smaller and hence it changes the distribution of electric field by reducing the current path. So, that the impedance matching is improved and for this the entire bandwidth is enhanced. The slot in the ground plane along the feed line also enhances the operating bandwidth. This is due to the coupling between the slot and the feedline which is responsible for impedance matching.

3. Experimented Result and Discussion

The mentioned crescent shape antenna was simulated with the High-Frequency Structural Simulator (HFSS) and Computer Simulation Technology (CST). The mentioned antenna was fabricated on the printed circuit board for practical observation. The measurement was performed in the Microwave Laboratory and Satimo Near Field Laboratory at the department of Electrical, Electronic and Systems Engineering (JKEES), UKM, Malaysia. For the measurement of the mentioned antenna, N5227A PNA Microwave Network Analyzer (10MHz- 67GHz) was used. The picture of the top layout, bottom layout, PNA, and Satimo lab during the measurement of the prototype is displayed in Fig. 3.

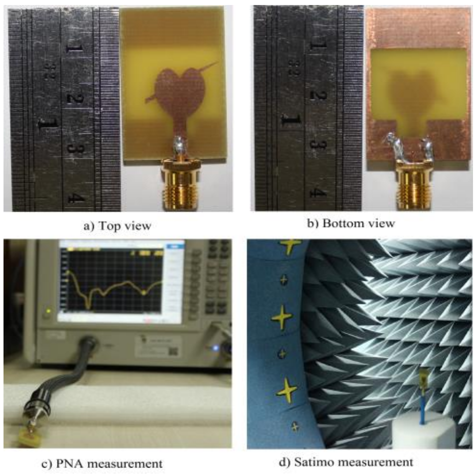


Fig. 3. Picture of the mentioned antenna after fabrication. a) Top view b) Bottom view c) PNA measurement d) Satimo measurement

The antenna performance has been experimented and analyzed using HFSS and CST. Data analysis software, Origin Pro is used to plot the simulated and measured data.
The impedance characteristic of the mentioned antenna is given by Fig. 4. The result shows 10 dB return loss bandwidth is from 2.90 to 10.70 GHz. Although there is a little disagreement between simulation and measurement, the results are identical throughout the entire band. The reason for the disagreement may be incorrect modeling of substrate losses and slotted ground plane. Another reason could be the fabrication process and the soldering of the connector to the feed line.

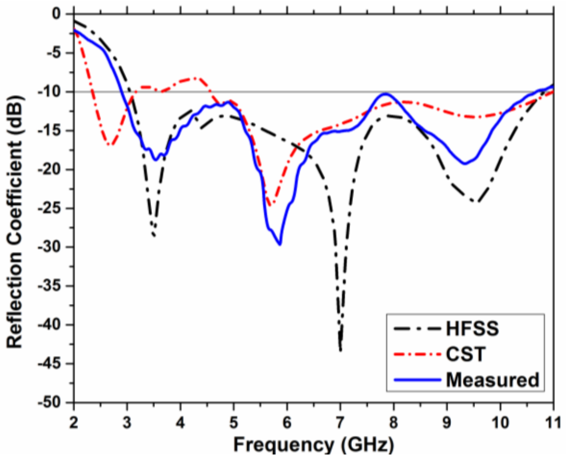


Fig. 4. Simulated and Measured S11 characteristics of the mentioned antenna.

Fig. 5. exhibits the VSWRs against the frequency of the mentioned antenna. The mentioned antenna shows a wideband performance from 2.90 to 10.70 GHz for VSWR≤2. Although there is a little discrepancy between simulated and measured VSWR, the results are uniform throughout the entire band.

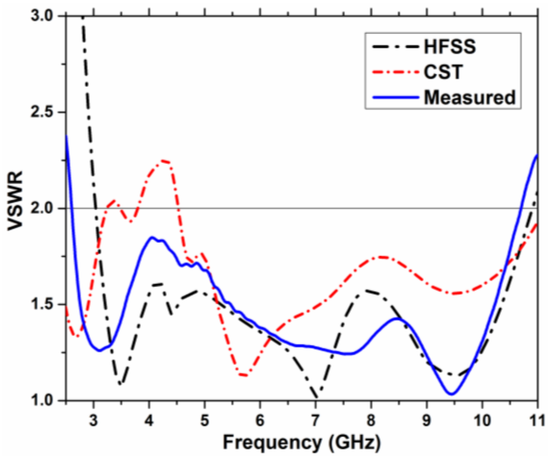


Fig. 5. Simulated and Measured VSWR of the mentioned antenna.

The simulated and measured gain of the mentioned, broken heart-shaped antenna is shown in Fig. 6. From the figure, it is investigated that the mentioned antenna has a maximum gain of 5.28 dBi. There is a little disagreement between simulated and measured results due to the fabrication process and the soldering the connector to the feed line.

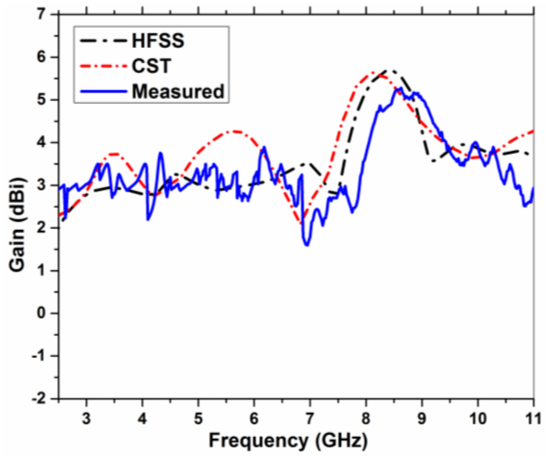


Fig. 6. Simulated and measured gain of the mentioned antenna.

Fig. 7 shows the simulated and measured efficiency of the mentioned antenna. The simulated result occupies a maximum efficiency of 94.30%, whereas the measured result varies a little due to the fabrication process and the soldering of the connector to the feed line. The lossy FR4 dielectric material is considered for the substrate for the mentioned antenna and this material affect the efficiency and the gain of the antenna. By occupying high priced microwave substrate instead of low priced and the lossy FR4 substrate, the efficiency and the gain of the mentioned antenna can be raised.

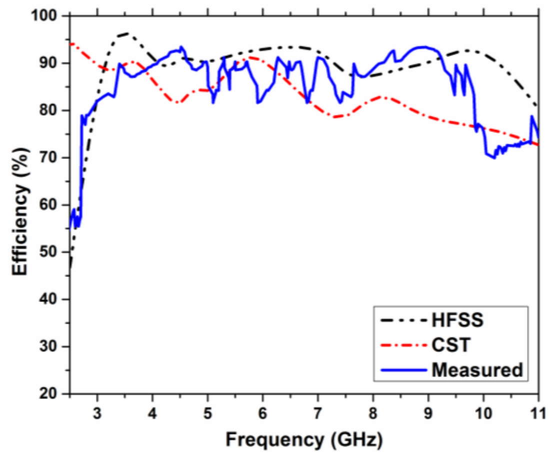
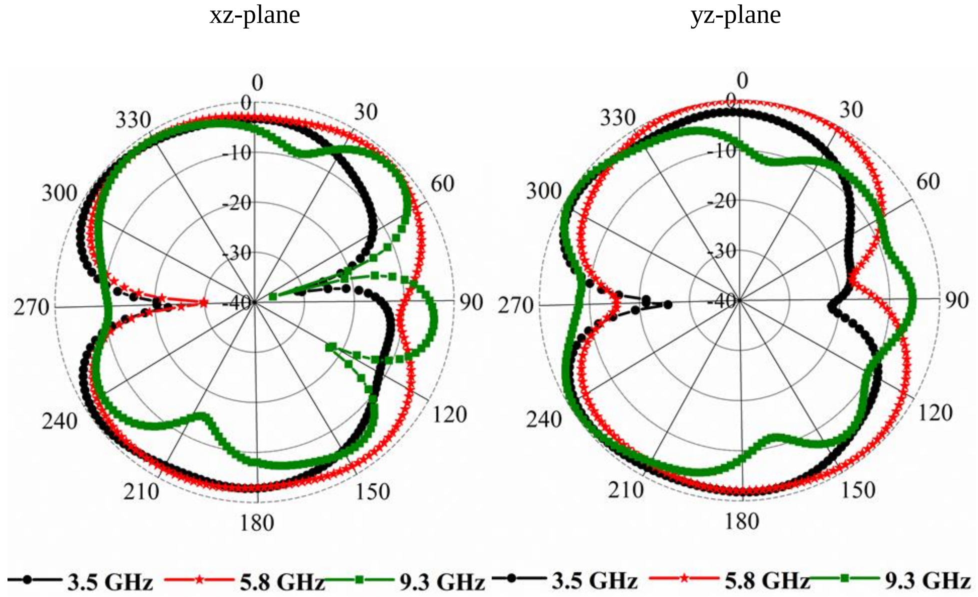


Fig. 7. Simulated and measured efficiency of the mentioned antenna

The radiation pattern of the mentioned, broken heart-shaped antenna for the same frequencies in xz-plane or E-plane (φ=0) and yz-plane or H-plane (φ=90) are displayed in Fig. 8a-b respectively. It is investigated that at 3.50 GHz, the radiation pattern of the mentioned antenna is omnidirectional both in E-plane and H-plane. At frequency 5.8 GHz, the radiation pattern of the mentioned antenna remains durable enough to be omnidirectional. The radiation pattern in E-plane turns directive at a higher frequency of 9.30 GHz for the excitation of higher order current. The results of Fig. 8 illustrate that the radiation patterns are outstandingly stable throughout the Ultrawideband.



a) b)

Fig. 8. Measured Radiation Pattern of the mentioned antenna a) xz-plane b) yz-plane

Fig. 9 shows the group delay of the mentioned, broken heart-shaped antenna. There is a little disagreement between the group delay of face to face orientation and side by side orientation. The group delay for side by side orientation is higher than that of the face to face orientation. In face to face orientation, the transferal line between two antennas is straight whereas the transferal line is indirect in side by side orientation. The distribution of the antenna group delay is linear in face to face orientation over the entire bandwidth.

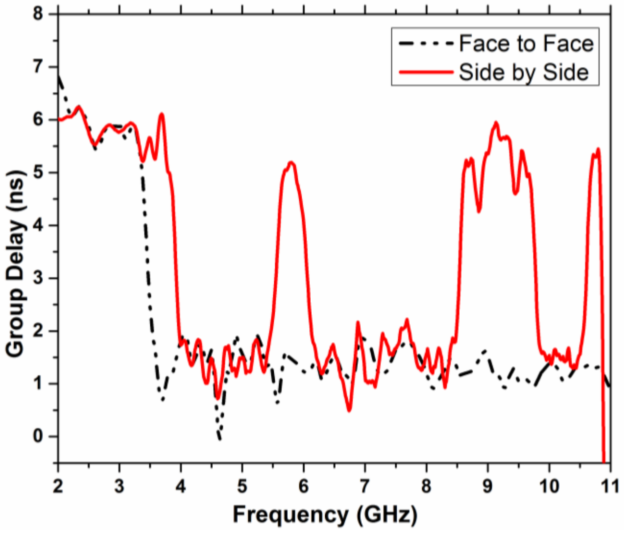
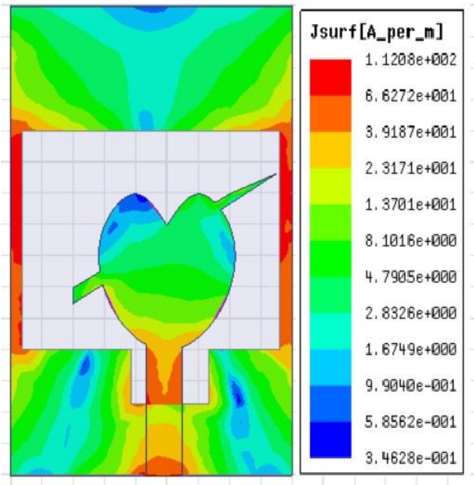
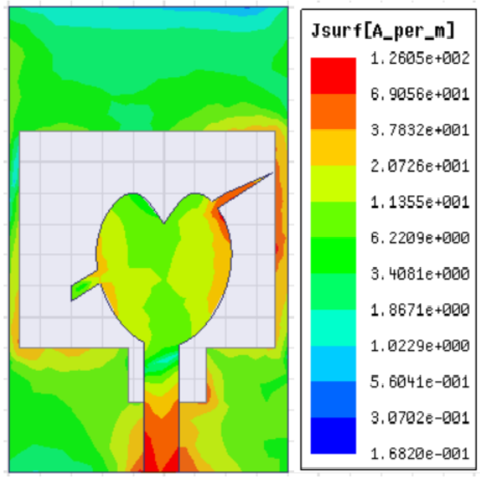


Fig. 9. Group Delay of the mentioned antenna

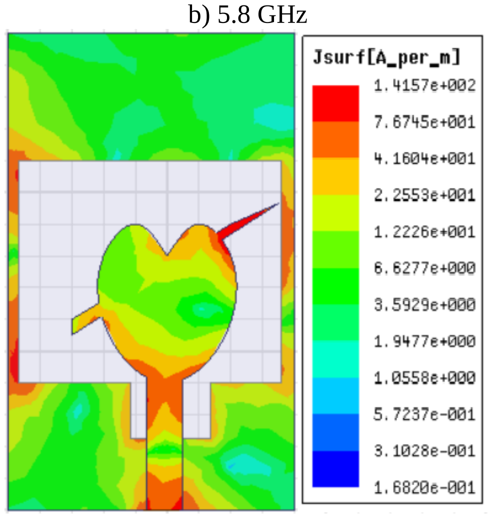
The surface current distribution on the radiating patch and slotted ground plane at frequency 3.5 GHz, 5.8 GHz, and 9.3 GHz are shown in Fig. 10a-c.



a) 3.5 GHz



b) 5.8 GHz



c) 9.3 GHz

Fig. 10. Distribution of surface current of the mentioned antenna at a) 3.5 GHz b) 5.8 GHz c) 9.3 GHz

From the figure, it is investigated that the radiating broken heart shaped patch and both left and right sides of the slotted ground plane provide a vital role in creating resonances and cover the wide bandwidth. The feedline also plays an important role to flow current. The mentioned antenna achieves a wide frequency because of the harmonic order of surface current flow both in the radiating patch and slotted ground plane.

Table 1. Comparison of the Bandwidth, Dimension, FBW, and Gain

Reference	Bandwidth GHz (S_{11} < -10 dB)	Dimension (L × W × h mm^3)	FBW (%)	Gain (dBi)
[1]	3.04 - 11.00	31 × 31 × 1.57	120.0	Maximum 7.0
[2]	2.70 - 26.00	40 × 48 × 1.5778	162.0	Maximum 4.50
[3]	3.10 – 11.0 with stop band 3.30 - 3.80 and 5.10 - 5.90	25 × 21 × 1.00	-	Maximum 3.00
[4]	4.00 – 19.10	25 × 26 × 0.50	-	Maximum 3.00
[5]	2.1 – 11.50	35 × 30 × 1.00	110.0	Maximum 9.90
[6]	3.00 - 11.20	22 × 24 × 1.60	115.5	Maximum 5.40
[7]	3.05 - 10.60 with 5 stop bands	31 × 25 × 1.60	-	1.62
[8]	2.70 - 9.30	40 × 50 × 1.60	110.0	Maximum 5.5
[9]	2.50 - 11.70	35 × 30 × 0.83	129.5	Maximum 4.0
[10]	2.78 - 9.78	50 × 42 × 1.50	111.5	Maximum 6.7
[11]	1.65-4.90	62.9 × 50 × 1.6	-	Not Mentioned
[12]	3.02-15.89	14.75 × 14.5 × 1.6	136.12	Maximum 1.60
Mentioned	2.90 – 10.70	30 × 18 × 1.60	115.0	Maximum 5.28

The comparisons between the mentioned, broken heart-shaped antenna and the referenced antennas in the literature review are shown in Table 1. The parameters of the comparison are bandwidth covered, antenna dimension, fractional bandwidth (FBW) and antenna gain. The mentioned, broken heart-shaped antenna has better bandwidth coverage than other antennas in reference though the mentioned antenna may have worst gain than some of the references. The mentioned, broken heart-shaped antenna can provide better compact characteristics having much smaller dimensions than the antennas in the references.

4. Conclusion

A novel compact and concise, broken heart shaped patch antenna with microstrip line is presented here. The antenna having a concise size of 30 mm × 18 mm on a low-cost lossy FR-4 PCB substrate achieves an impedance bandwidth from 2.90 GHz to 10.70 GHz maintaining VSWR≤2. The simulated and measured results exhibit that the mentioned, broken heart-shaped antenna attains a maximum gain of 5.28 dBi, durable omnidirectional directivity, linear distribution of group delay, and considerable efficiency that originate the mentioned antenna competent for the ultra-wideband communication applications.

Acknowledgment

The authors would like to thank the department of Electrical, Electronic and Systems Engineering (JKEES), Universiti Kebangsaan Malaysia (UKM) and Ministry of Higher Education Malaysia (Grant No. AP-2015-007), for the sponsorship in this work.

References

[1] M. Mahmud, M. Islam, and M. Samsuzzaman, "A high performance UWB antenna design for microwave imaging system," *Microwave and Optical Technology Letters*, vol. 58, pp. 1824-1831, 2016.

[2] C. F. Torres, J. M. Monroy, H. L. Morales, R. C. Pérez, and A. C. Tellez, "Heart shaped monopole antenna with defected ground plane for UWB applications," in *Electrical Engineering, Computing Science and Automatic Control (CCE), 2014 11th International Conference on*, 2014, pp. 1-4.

[3] J. Shen, C. Lu, and J. Zhang, "Heart-shaped dual band-notched UWB antenna," in *Antennas and Propagation (APCAP), 2014 3rd Asia-Pacific Conference on*, 2014, pp. 487-490.

[4] G. Isik and S. Topaloglu, "A Compact Size 4–19.1 GHz Heart Shape UWB Antenna with Triangular Patches," *International Journal of Antennas and Propagation*, vol. 2013, 2013.

[5] T. Yang and X. J. Tian, "A novel heart- shaped monopole antenna for UWB and RFID applications," *Microwave and optical technology letters*, vol. 53, pp. 2288-2291, 2011.

[6] R. Azim, M. T. Islam, and N. Misran, "Compact tapered-shape slot antenna for UWB applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 10, pp. 1190-1193, 2011.

[7] M. M. Islam, M. T. Islam, M. Samsuzzaman, and M. R. I. Faruque, "Five band- notched ultrawide band (UWB) antenna loaded with C- shaped slots," *Microwave and Optical Technology Letters*, vol. 57, pp. 1470-1475, 2015.

[8] S. Hu, Y. Wu, Y. Zhang, and H. Zhou, "Design of a CPW-Fed Ultra Wide Band Antenna," *Open Journal of Antennas and Propagation*, vol. 1, p. 18, 2013.

[9] M. N. Srifi, S. K. Podilchak, M. Essaaidi, and Y. M. Antar, "Compact disc monopole antennas for current and future ultrawideband (UWB) applications," *IEEE Transactions on Antennas and Propagation*, vol. 59, pp. 4470-4480, 2011.

[10] J. Liang, C. C. Chiau, X. Chen, and C. G. Parini, "Study of a printed circular disc monopole antenna for UWB systems," *IEEE Transactions on antennas and propagation*, vol. 53, pp. 3500-3504, 2005.

[11] T. Alam, M. R. I. Faruque, M. T. Islam, and B. Malaysia, "Printed circular patch wideband antenna for wireless communication," *Informacije MIDEM*, vol. 44, pp. 212-217, 2014.

[12] R. Azim, M. T. Islam, N. Misran, and A. T. Mobashsher, "Compact UWB planar antenna for broadband applications," *Informacije MIDEM*, vol. 41, pp. 37-40, 2011.